UNIT 2.3 COMMUTATION

OBJECTIVES

After completion of this unit you will be able to understand:

- cause of sparking in DC machines
- reactance voltage
- emf equation
- contribution of commutating poles
- reason for use of high resistance brushes

STRUCTURE

1. Introduction
2. Cause of sparking
3. Reactance voltage
4. Emf commutation
5. Commutating poles
6. Use of high resistance brush
7. Summary
8. Self Assessment Exercise

1. INTRODUCTION

Owing to the thinness of the insulation between the commutator segments, it is obvious that a brush may be in contact with two or more segments at the same instant. Hence, if an armature coil has its ends connected to two of these segments, the coil will be short-circuited by the brush, and as the armature rotates, each coil will, of necessity, be short-circuited. This period of short-circuit is the period during which the current is being delivered from the commutator segments concerned, to the brush, and it is, therefore, called the period of commutation.

By commutation we mean the changes that take place in an armature coil during the period that it is short-circuited by a brush. These changes are illustrated in figure 1, the winding being represented as a ring winding for simplicity. Currents of magnitude I amp are flowing to the brush through the armature from the right and left, the total current delivered by the brush, therefore, being 2I amps. In the first diagram the coil B is on the point of being short-circuited, and it is carrying, in a direction from left to right, half the current delivered by the armature to the brush. The second diagram shows the same coil in the middle of the short circuit period, from which it will be seen that it is possible for the current I flowing from right and left to reach the brush without passing through this coil. In the third diagram, the same coil B is shown immediately after short circuit, and in this position it is, or should be, carrying the full current in a direction from right to left. We thus see that during the short circuit period, the current in the short-circuited coil must be reversed and brought up to its full value in the reversed direction.

2. CAUSE OF SPARKING

If the current in coil B has not attained its full value in the position shown in the third diagram, then since the coil C is carrying the full current, and this current must reach the brush, the difference between the currents carried by coil B & C has to jump from the commutator bar to the brush in the form of a spark. Thus suppose that the armature conductors are carrying a current of 50 amps, but the current in coil B has only reached 40 amps, then by the end of short-circuit, the difference of 10 amps will have to jump to the brush in the form of a spark. The energy in these sparks may be very high, the result being a very high temperature rise of the commutator, and pitting and roughening of the segments in a very short time.

The cause of sparking at the commutator is, therefore, the failure of the current in the short-circuited coil to reach the full value in the reversed direction by the end of short-circuit. Suppose the current in each conductor is I amp, then what is required is that the current shall change from +I to -I during the time of short-circuit. This is represented in fig.2 in the form of a graph. "Curve I" shows what happened when the current does not reach the full value; "curve II" shows the ideal, a gradual change of current from +I to -I; "curve III" shows what may happen if one of the remedies for under commutation in overdone and the current in the reversed direction is forced up to a value greater than I.

3. REACTANCE VOLTAGE

The difficulty experienced by the current in attaining the full value in the reversed direction by the end of short-circuit, is due to the fact that the current in the short-circuited coil is changing. When the coil is carrying a steady current, this current produces a magnetic field of constant strength, and the number of lines of force linking with, or threading, the coil is constant. Under these conditions there is no change in number of lines of force and consequently there is no e.m.f. induced in the coil other than that produced by the rotation of the coil in the main field. But when the current changes in magnitude, or direction, or both, then there is a change in the number of lines of force linking with the coil, and in consequence an e.m.f. is induced. The production of this e.m.f is thus exactly similar to the production of an e.m.f in a coil by thrusting a magnet in to it, the only difference being that the necessary change in the number of lines of force linking with the coil is produced, not by the introduction of a magnet, but by a change in the current carried by the coil. Like all induced e.m.f., this induced e.m.f. is a back e.m.f., it tries to stop the change of current. Now the direction of current is from left to right in the first diagram of fig.1, and right to left in the third, and so the induced voltage acts in the original direction of the current, thereby preventing it from attaining its full value in the reversed direction by the end of short-circuit.
This induced voltage is called the reactance voltage.

4. E.M.F. COMMUTATION

The cause of difficult commutation is the reactance voltage, and follows that if this voltage could be neutralized, spark-less commutation would be achieved. In order to neutralize the reactance voltage it is necessary to induce in the short-circuited coils another e.m.f which is opposite in direction to the reactance voltage, and, therefore, in same direction as the current when reversed. The old method of achieving this consisted in rocking the brushes forward until they were some way ahead of the magnetic neutral plane. The result of this was that the short-circuited coils were located ahead of the neutral plane, and were therefore, under the influence of the next pole further ahead. This pole induced an e.m.f in them in the required direction, because after commutation they would be entirely under its influence until they reached the next brush. There are two very serious objections to this method. The first is that with a changing load the position of the magnetic neutral plane is continually changing, thus necessitating the continual adjustment of the brush position. With modern dynamos it is invariably specified that they shall operate spark-less at any load between zero and full-load with a fixed brush position. The second objection is that the magnetic field which induces the commutating e.m.f. is the fringe of flux under the leading pole tip, and we have seen in a previous lesson that this flux is gradually wiped out as the load increases. With heavy leads it is, therefore, necessary to give the brushes a very large load, unless some other method of securing spark-less commutation is adopted.

5. COMMUTATING POLES

In order that a commutating e.m.f may be induced in the short-circuited coils it is necessary that these coils shall be situated in a magnetic field, called the commutating field. Instead of making use of the fringe of flux under the leading tips of the main poles, the modern method is to employ separate poles called commutating poles, or interpoles. These are narrow poles placed mid-way between the main poles and excited, so that each one has the same polarity as the next main pole further ahead, thereby giving a commutating field of the right kind. This is illustrated in fig.4. By the use of these poles the necessity for rocking the brushes forward with increasing load is done away with and, as a result, the machine can be worked with a fixed brush position. Now the reactance voltage is proportional to the change of current, which takes place in the short-circuited coil, and this in turn is proportional to the current delivered by the armature. The commutating e.m.f and the commutation magnetic field produced by the interpoles must therefore be proportional to the armature current. For this reason, the exciting current through the interpole windings must not be kept constant but must vary with the load. This is achieved by series excitation of the interpoles; that is, their exciting coils are connected in series with the armature, thereby carrying a current equal to the armature current. For small machines the exciting coils consist of insulated cable capable of carrying the full armature current, but with very large machines delivering very large currents the exciting coils consist of very heavy copper strips wound on edge. An interpole of this type is shown in fig.3. In extreme cases the coil may consist of a heavy copper casting. The next illustration (fig.5) shows a complete stator with main and commutating poles.

It will be readily understood that for a given armature current there is proper value of the commutating field, and that it is possible for this field to be too strong. In such a case the reversed current in the short-circuited coil is forced to too high a value by the end of short-circuit, and sparking at the commutator takes place in the reversed direction. This is called over-commutation and is represented graphically by "curve III" in fig.2.

6. USE OF HIGH RESISTANCE BRUSHES

A second method of obtaining good commutation is to use brushes having a high contact resistance when pressing on the commutator segment, since brushes of this kind help to force the current coming up to the brush from the leading side of the armature, through the short-circuited armature coils. This can be understood from Fig.6 in which the winding is again represented as a ring winding for simplicity. The total current collected by the brush from the armature is represented as 2I, and one-half of this, namely I amp comes from the left and I amp from the right. The current I coming from the left reaches the brush via commutator segment a and it has to traverse the contact resistance r1 between this segment and the brush. It has also an alternative path to the brush via the short-circuited coil and across the segment b, the resistance in this path being the contact resistance r2 between segment b and the brush. At the commencement of short-circuit the brush will be mainly in contact with segment b and will only just touch segment a, with the result that the resistance r1 will be very high (because of the very small area of contact) while r2 will be low. A large portion of the current coming from the left will, therefore, at this instant, take the lower resistance path through the short-circuited coil. As the commutator moves past the brush, the area of contact with segment a gradually increases, while that with segment b decreases and therefore, contact resistance r1 gradually decreases while r2 increases. There is thus a gradual tendency for that portion of the current I coming from the left and flowing through the short-circuited coil, to leave the coil and take the direct path to the brush across the segment a. This is as it should be, because the current coming from the left is not in the reversed direction and it is necessary to eliminate it from the short-circuited coil as quickly as possible. Now consider the current I coming up to the brush from the right. There are also two parallel paths open to this current as soon as it reaches the commutator segment b. The first is straight across the segment b to the brush and the second is round the short-circuited coil and then across the segment a. With brushes having a low contact resistance with the commutator there is no inducement for the current to take this second path. With carbon brushes, which have a high contact resistance, more and more of the current flowing to the brush from the right hand will be shunted round the short-circuited coil as the segment b passes the brush, because, as we have seen, the contact resistance r2 is gradually increasing, where-as the resistance r1 is gradually decreasing. Finally when the period of short circuit is almost ended, the brush will only just be touching segment b and r2 will be very high, becoming infinitely great when the segment has left the brush. The whole of the current I from the right will then be flowing through the short-circuited coil. Furthermore, this current is in the necessary reversed direction.

For the above reasons carbon brushes have almost entirely replaced the copper brushes which used to be used with older machines. The disadvantage of carbon brushes is that they can only be worked at a current density of about 40 to 50 amperes per sq. inch as compared with 150 to 200 for copper brushes. This necessitates a larger area of contact at the brush face and, therefore, a longer commutator.

The properties of a few grades of brush are shown in the following table: -

BRUSH TYPE	MAX. CURRENT DENSITY (amp/in.^{2})	MAX.CONTACT RESISTANCE (ohms/in.^{2})	PRESSURE ON COMMUTATOR (lb/in^2)
Copper Ordinary.	200	0.003	1.5
Carbon	40	0.04	2.0
Electro- graphite	60	0.02	2.0

For the same area of brush, (Contact resistance of carbon brush) / (Contact resistance of copper brush)= $^{0.04}/_{0.003}$ =13

But for the same current collected, the contact area of the carbon brush must be 200/40 = 5 times the area of the copper brush, because of its smaller working current density. Hence, since the contact resistance is inversely proportional to the contact area, we have, for the same current collected, (Contact resistance of carbon brush)/ (Contact resistance of copper brush)=13/5=2.6

This is sufficient to give improved commutation.

If a machine gives difficulty with commutation, it can often be cured by fitting new brushes having a higher contact resistance than the old ones. Brushes of high resistance often have a high coefficient of friction, and if such a change is made it is necessary to make sure that the armature temperature rise does not become too much high because of the increased brush friction. The specification for machines normally limits the temperature rise of the commutator to 45^{O}C.

7. SUMMARY

Information has been given about commutation of DC machines, use of high contact resistance type carbon brushes, cause of sparking and how to avoid it, which would prove to be important to understand behavior of DC machines. The contribution of commutating poles to improve commutation has been described so that their importance is appreciated.

8. SELF-ASSESSMENT EXERCISES

1. Justify the use of high contact resistance type carbon brush in traction machines for improving commutation.
2. What do you mean by emf commutation? How does it made proper by using commutating poles?
3. Why an Electro-graphite carbon brush is used in traction machines? Justify.